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CONSTRUCTION ENGINEERING RESEARCH LAB (ARMY) CHAMPAIGN
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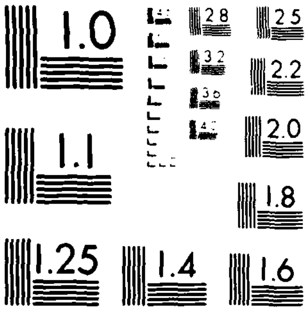

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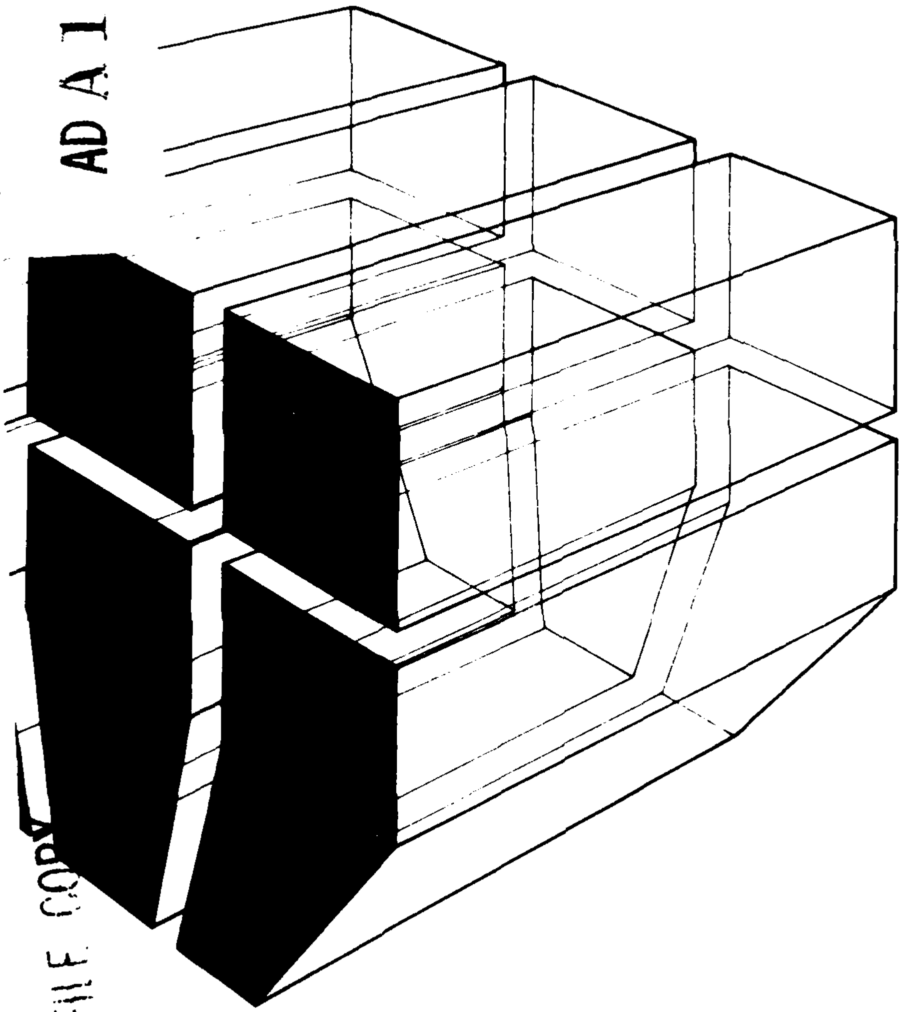
TECHNICAL REPORT M-324
October 1982
Combat Engineering Strategy

SUMMARY OF REPAIR TECHNIQUES FOR ALUMINUM BRIDGING



by
Derrick Brockman
Robert A. Weber

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This report provides the results of an investigation designed to recommend joining processes which could be used in the field to repair aluminum bridging. A literature search was conducted to identify the various aluminum repair processes available. The merits of each method as a field repair procedure were then evaluated.

The available systems identified were gas metal-arc welding, shielded metal-arc welding, gas tungsten-arc welding, gas welding, resistance spot welding, adhesive bonding, electron beam and laser welding, explosion welding, and ultrasonic welding. These pro-

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cesses were evaluated in terms of their strength, corrosion resistance, ease of use, safety, whether their equipment was adaptable to use in the field, and economy.

Based on these criteria, four processes were identified as being acceptable for use in the field. These were: gas metal-arc welding, gas tungsten-arc welding, adhesive bonding, and explosion welding.

FOREWORD

This research was conducted for the U.S. Army Engineer School and the Directorate of Military Programs, Office of the Chief of Engineers (OCE), under Project 4A762731AT41, "Military Facilities Engineering Technology"; Task Area D, "Combat Engineering Strategy"; Work Unit 052, "Improved Field Joining Techniques for Aluminum Alloys." The U.S. Army Engineer School Technical Monitor was CW3 B. Fenhagen.

This work was performed by the Engineering and Materials Division (EM) of the U.S. Army Construction Engineering Research Laboratory (CERL). Mr. R. A. Weber was the CERL Principal Investigator. Dr. R. Quattrone is Chief of CERL-EM.

COL Louis J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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FIGURES

SUMMARY OF REPAIR TECHNIQUES FOR ALUMINUM BRIDGING

1 INTRODUCTION

Background

As part of a program to make its forces lighter and more mobile, the Army has introduced aluminum into as much of its equipment as possible. Tactical bridging systems are one area that is now using extensive quantities of aluminum. Consequently, many of the aluminum repairs which Army personnel must make in the field are on these systems. Previous work identified the types of aluminum alloys used for the three major tactical bridging systems.[1]

Mobile Assault Bridge (MAB)

The MAB consists of three major components: the transporter, the interior bay (bridge) superstructure, and the end bay (ramp) superstructure (Figures 1, 2, and 3). The transporter, an amphibious vehicle mounted on a 4 X 4 chassis, has a riveted and welded hull and a watertight, three-man cab. The hull is constructed of 1/8-in. (8.2-mm) aluminum plate on the sides and deck, and 3/16-in. (4.8-mm) aluminum plate on the bottom, bow, and stern. The interior bay superstructure is constructed of welded steel girders with an extruded aluminum decking, while the end bay superstructure is constructed of aluminum girders and aluminum decking. The aluminum used is 5086 alloy, a magnesium alloy whose strength is developed by strain hardening. Magnesium up to about 5 percent makes it a strong, highly weldable material. It has excellent weld joint efficiency because it retains a high percentage of its strength after welding. These properties, plus its good corrosion resistance, make this alloy ideal for bridge structural members.

Improved Float Bridge (Ribbon Bridge)

The ribbon bridge's major components are the transporter, the interior bay pontons (Figures 4 and 5), and the ramp bay pontons (Figures 6 and 7). The transporter is a standard 5-ton truck with a special A-frame for off- and on-loading the bay sections (Figure 8). The interior and ramp bay sections are constructed of four aluminum pontons hinged in three places so that the bays can be accordian-folded during transport. The pontons are fabricated from 5456 aluminum alloy. The decking is 6061 aluminum alloy on both the interior and ramp bays. The major alloying element in the 5456 aluminum is magnesium; like the 5086 alloy, its strength is developed by strain hardening. It has excellent weldability and high weld joint efficiency. Magnesium and silicon are the major alloying elements of the 6061 alloy; its strength is developed by a thermal treatment after the product has been rolled to the desired shape. The 6061 alloy is one of the most versatile of the heat treatable alloys. It has good weldability, but has a joint efficiency of only about 65 to 75 percent after fusion welding unless a post-weld heat treatment is used.

Medium Girder Bridge (MGB)

The MGB is made up of panels, beams, and girders. The parts are transported by trailer (Figures 9 and 10) to the erection site, where they are manually assembled into a bridge span (Figure 11). The bridge is completely fabricated from 7005 aluminum alloy (a zinc-magnesium alloy). This alloy is a natural-aged material, requiring about 1 month after fabrication and welding to gain its maximum strength. Its weldability is good, with joint efficiency approaching 90 percent after 1 month. This bridge system is the newest of the three and consequently has been used very little by the troop units.

Aluminum is readily joined by welding, brazing, soldering, adhesive bonding, or mechanical fastening. Often, aluminum is joined by means of conventional equipment and techniques used with other metals. Each process has certain advantages and limitations. The alloy, joint configuration, strength required, appearance, and cost dictate the choice of process.

Repair of aluminum parts in the field is quite different from shop repair or even theater of operations repair. Repair methods must be easy to use, require minimal training, and be done quickly to return the part to service rapidly.

Objective

The objectives of this investigation were to (1) survey all available aluminum alloy joining methods, (2) evaluate each method on its merits as a field repair procedure for bridges, and (3) recommend the most feasible methods for developmental investigation and possible implementation.

Approach

A literature search was conducted to assess various welding and joining repair techniques for aluminum.

[1] R. A. Weber, *Identification of Problems Encountered in the Field Welding of Aluminum*, Technical Report M-301/ADA109697 (U.S. Army Construction Engineering Research Laboratory [CERL], 1981).

The procedures and equipment used with these methods as well as any problems with their potential use in the field were identified. Processes that were deemed suitable for use in field repair were recommended.

Mode of Technology Transfer

It is recommended that the information in this report be disseminated as changes to publications: TM 5-5420-209-12, *Technical Manual Operator and Organizational Maintenance Manual, Improved Float Bridge (Ribbon Bridge)*, TM 5-5420-210-12, *Technical Manual Operator and Organizational Maintenance Manual Transporter, Mobile Floating Assault Bridge/Ferry Condec Corp. Model 2270, FSN 5420-491-6330*; and TM 5-5420-212-12, *Technical Manual Operator and Organizational Maintenance Manual, Medium Girder Bridge*.

2 AVAILABLE REPAIR PROCESSES

Evaluation Criteria for Joining Methods

Both the weld application and the service environment of the weldment (i.e., how and where it will be used) often determine alloy and temper selections as well as the joining method used for aluminum repairs. The choice of method may also depend on whether the joint will be made in the shop or in the field, and whether the part is small enough to be moved close to the welding equipment. Another consideration is the performance of the part after joining; important characteristics in this area are joint strength, impact resistance, fatigue resistance, corrosion resistance, and performance under special service conditions. Safety, economy, equipment portability, and ease of use must also be considered.

With these considerations in mind, a literature search of available repair processes was conducted. The references list the sources used for this investigation.

Welding Processes

Gas Metal-Arc Welding

Gas metal-arc welding (GMAW) uses an automatically fed bare electrode (Figure 12). The arc and weld pool are enveloped by a stream of inert gas. This process can deposit large amounts of filler metal during a relatively short time. The costly process of slag removal is eliminated because no fluxes are associated with the process.

Because the process is semi-automatic and the welding gun is easily manipulated, little operator effort is needed for welding in any position (e.g., flat, horizontal, etc.) either in the field or the shop. Trainees of normal ability can produce good-quality GMAW in aluminum in less time than they would using shielded metal-arc steel welding.

The high-current-density process used in GMAW is best suited for parts which can be located or positioned for downhand, fully automatic welding. Tank cars, structural fillet welding, ship deck and bulkhead welding, bridge girders, rail car frames, and heavy-wall pipe are typical units which would use this process.

The basic equipment required of GMAW for aluminum is:

1. Welding gun, control unit, wire feed, and hoses for water and gas
2. Current contactor or field relay
3. Water supply (except for small air-cooled guns)
4. Power source (DC)
5. Inert gas supply
6. Filler wire.

Shielded Metal-Arc Welding

The shielded metal-arc welding process has no external shielding gas because the electrodes have a flux coating (Figure 13). Many factors must be considered if shielded metal-arc welding will be used for aluminum; these include moisture, preheating, flux, and cleanliness of electrode and work. When used in the field, the presence of moisture in the electrode coating is a major cause of weld porosity. Also, the flux coating on the electrode is very tenacious. It takes a skillful operator to prevent entrapment in the weld and a lot of effort for the post-weld removal.

One difficulty with shielded metal-arc welding is the formation of a fused flux coating over the end of the electrode; this is caused by interruption of the arc. Reestablishing a satisfactory arc is impossible until this formation is removed. This is usually done by striking the rod against the work or other surface.

Gas Tungsten-Arc Welding

Gas tungsten-arc welding (GTAW) uses heat from an arc between the work and a nonconsumable tungsten electrode (Figure 14). The arc is enveloped by a stream of inert gas. Weld metal is added, using a rod for thick welds (greater than 1/4 in. [6.3 mm]). This process produces the best-quality welds. The shield gas is usually argon for alternating current (AC) GTAW and helium for direct current straight polarity (DCSP). The inert atmosphere prevents oxidation of the molten aluminum, so that no welding flux is required; also, costly post-weld flux removal is eliminated.

Weldable aluminum in thinner gages (0.015 to 0.125 in. [.38 to 3.2 mm]) may be manually GTAW-welded using various joints without filler metal with AC. Edge preparation is necessary when thicker sections are welded. Consequently, GMAW is used for larger grooves because they can be filled more efficiently than with GTAW. Heat produced by the heavy current flux into the work during the straight polarity portion of the AC cycle produces depth of penetration of the AC weld. This heat is also concentrated in a relatively small area. When using GTAW, particular care should be taken to avoid "bridging" of the molten pool at the root of the joint. When this occurs, full root penetration is not obtained.

Gas Welding

Gas welding (GW) uses an oxy-acetylene, oxy-hydrogen, or other oxy-fuel gas flame to melt the parent metal and usually filler metal to make the weld (Figure 15). This process requires great operator skill and is very slow. The method involves the combustion of a gas, usually acetylene, with oxygen. An active flux must be used to shield the molten metal surface from oxygen in the gas mixture and in the atmosphere. Filler metal is added as required.

Advantages of using GW include low-cost equipment that is readily available and field-portable. In some applications, oxy-gas is still economical for welding, particularly for thinner gages of aluminum, ranging from about 0.032 to 0.064 in. (.05 to .1 mm).

One disadvantage of GW is that it produces a flux residue, which is a potential source of corrosion or of weld defects in multipass welds. The flux must be removed after welding. Another disadvantage is that GW produces more distortion than arc welding because a wider area is heated and welding speeds are slower. These conditions generally result in higher costs in comparison with arc welding methods.

The slower heating rate of gas welding, as compared with arc welding, results in a longer heating period. This is detrimental to heat-treatable aluminum alloys such as 6061 and 6063. Alloys 5083 and 5086, developed for special welding applications, have greatly minimized the problem of strength loss caused by heating and slow cooling during repair.

GW is still used in some furniture and product applications and for small jobs where capital outlay for welding equipment must be minimized. It is the obvious choice for use in the field, where electric power lines or portable generators for arc welding are not accessible.

Resistance Welding

Resistance welding forms localized areas of weld metal between workpieces by combining the heat of resistance to electric current with mechanical pressure (Figure 16). Once the machine is installed, very little operator skill is required. When large numbers of joints are mass-produced, it is often more economical than other welding methods. The aluminum meets at the point of pressure on the interface when a high amperage current is passed through the work and through the point of contact between the metal surfaces. Electrode force, current, and time are accurately controlled to obtain the conditions needed to produce a satisfactory resistance weld in aluminum. Compared with steel welding, electrode force must be controlled to a higher degree for aluminum joints. A much higher current is needed to generate the heat required to form the weld nugget for aluminum than for steel, because of aluminum's higher electrical and thermal conductivities. The typical electrical resistance through pieces of aluminum lapped or "sandwiched" for making a spot weld is about 10 microhms. For steel it is about 75 microhms. Steel resistance welding of various gages and alloys generally requires a current range between 3000 and 15,000 amperes, while for aluminum alloys of various thicknesses, the range is about 10,000 to 300,000 amperes.

The heat (H) produced in electrical resistance welding processes is proportional to I^2 Rt, where I is the current, R is the resistance, and t is the time during which the welding current flows. $H=I^2Rt$ is Joule's Law. There are various types of resistance welding repair processes. These include cross-wire welding, projection welding, mesh welding, spot welding, and rollspot welding. Seam welding is a special form of spot welding in which a row of spots is made with precise control; the weld nuggets overlap to form a pressure-tight seam.

Adhesive Bonding

Adhesive bonding is more than just a substitute for other joining techniques. The metal oxide film on the s' 'ace of alu- ium and aluminum alloys forms strong, durable bonds with metal-bonding adhesives. The ease of joining and inherent desirable chemical and physical properties, such as high strength-to-weight ratio, resistance to corrosion, and formability, account for the widespread use of adhesively bonded aluminum assemblies. Adhesives are used increasingly for joining aluminum products such as sheets, extrusions, tubes, structural shapes, foil, plates, wires, rods, bar forgings, and castings. Figure 17 shows a variety of joint designs used with adhesive bonding.

Many types of adhesives are used in the field for repair techniques; these include epoxies, Phenolic adhesives, Elastomeric-based adhesives, different types of rubber adhesives, and polyvinyl adhesives.

Safety precautions must be used to prevent health problems associated with the solvents. Environmental health problems are ordinarily associated with the materials used for surface preparation of the metal, with the adhesive materials themselves, or both.

One advantage of adhesive-bonded joints is their inconspicuousness; sometimes they are almost invisible. Actual or potential applications for adhesive bonding are building products, structures, appurtenances, sporting and automotive equipment, aircraft, and military uses.

Electron Beam and Laser Welding

Electron beam welding is a superior process for joining aluminum. The term "superior" refers to the narrow fusion- and heat-affected zones and to the production of consistently high-quality aluminum welds provided by this process. Figure 18 is a schematic diagram of the electron beam welding process. However, use of this process for aluminum welds is not recommended unless the following essential economic considerations are taken into account: size of workpiece vs. chamber size, pumpdown times, and original cost of equipment.

Electron beam welded aluminum is generally pure and dense. Porosity and inclusions do not occur where proper technique and reasonably clean surfaces are used. Often, the mechanical properties of electron beam welds remain unchanged from those of the parent metal. The microstructure of the base metal adjacent to the fusion zone is much less affected than in GTAW welding.

The heating rate in electron beam welding is extremely high. However, in most cases, the total heat input into the workpieces is relatively small. Although there are now several types of electron beam welding equipment, most operate on the same basic principle. For mass production work, this process requires very little operator skill once the machine is set.

Laser (light amplification by stimulated emission of radiation) light is generated by a process in which an ensemble of atoms is excited and coherent light is emitted (Figure 19). Although rapid advances in laser technology have made it available for a number of production joining jobs, its range of application is still limited. However, laser welding is making significant contributions, some of them unique: for example, it is used for packaging aerospace electronic components, which requires consistent weld reliability. Also, subminiature and microminiature electronic packaging design has been increasingly applied to computers, meters, sensors, and many other devices, using laser welding.

Explosion Welding

Explosion welding is a solid-state bonding process in which the weld is produced by plastic flow of the metal. This process is now being used for many applications. The advantage of this process is that it joins two dissimilar metals, such as steel and aluminum, that cannot be welded by any other arc welding process. The process is fast and economical for certain joint configurations, such as lap and tube-to-tube sheet welds. This process can also be used for cladding. Figure 20 is a simplified sketch of an explosive welding assembly.

Successful explosion welding requires (1) sufficient impact pressure to produce surface ripples, and (2) an angle of impact large enough to permit the ripple to propagate. Also, this technique requires a number of safety precautions and a great deal of operator skill.

Ultrasonic Welding

Ultrasonic welding (Figure 21) is a process for joining similar and dissimilar metals by introducing high-frequency vibrating energy into the overlapping metals at the area to be joined. Spot, seam, and ring welds can be made using moderate pressure. However, this process is limited to thin section materials (<0.1 in. [2.5 mm]) and requires a fair amount of operator skill.

Ultrasonic welding is a solid-state bonding process. Its growing popularity for aluminum fabrication is due largely to the following characteristics: (1) it produces the best bonds between aluminum and dissimilar metals (within gage limitations); (2) it is the best available process for reliable, accurate control in welding thin aluminum foil and fine wire; and (3) it can join many heat-sensitive materials and components with no adverse heat effects.

The process requires a large electrical input to operate and access to both sides of the weld. The equipment setup is similar to that used for resistance welding equipment.

3 DISCUSSION OF FIELDABILITY

Arc Welding Processes

The arc welding processes are currently the only ones the Army uses for repairs. The engineer welders are trained at the Ordnance School for basic hands-on experience and at Fort Leonard Wood for the advanced levels. The processes are fairly easy to use, but require some experience. The 7005 alloy, which is welded by these processes, must be aged after welding to regain its strength; however, current procedures are to use the alloy for repairs and then use the repaired item in the as-welded condition. The as-welded strength is fairly high (about 40 ksi tensile strength) if the repair is done properly, and the reduction in strength may not be detrimental. A proposed repair procedure would use a large patch and spread the welding over a large area. This would reduce the stress on any one part of the fillet weld. This procedure is satisfactory for puncture wounds but not for cracks in Tee joints, which predominate in the MGB.

The GMAW system is suitable for field and theater of operations repairs. DC-GTAW is also satisfactory for heavier sections more than 1/8 in. (3.2 mm) thick, while AC-GTAW is satisfactory for the thin sections. The GTAW process is slow, but provides good-quality welds. SMAW welding of aluminum is not yet satisfactory because the electrodes are difficult to operate and require a great deal of operator skill. They also require much more care in cleaning the weld joint.

Gas Welding

The gas welding process is unsatisfactory because it is very slow and requires a great deal of operator skill. In industry, very little gas welding is done because of the high cost per joint both in labor and in time. Electric arc welding processes have nearly replaced gas welding.

Resistance Welding

Resistance welding is suitable for repairing most thin section materials, but not for plate and wire. The power requirements and the size and weight of the equipment make fielding of this process prohibitive.

Adhesive Bonding

Adhesively bonding a patch plate over a puncture wound to make a hull or ponton watertight would be an easy repair. The materials could be made available in a kit form similar to a patching kit for a rubber tire. Adhesive bonding for stress cracks would require engineering an adhesive/plate combination that would withstand the stresses applied. This would require more work but would be a satisfactory repair method for a large number of the defects encountered in bridges.

Electron Beam and Laser Welding

Electron beam and laser welding processes are not suitable for field use at present because of the size of the equipment and the need for auxiliary equipment. The electron beam welding process requires that the piece to be welded be placed in a vacuum. Without the vacuum, the electron beam attenuates rapidly in air. Laser welding requires very close control over the location of the focused beam and its relative position to the surface of the weldment. At present, this requires very sophisticated equipment which does not lend itself to field applications. Neither system is practical for field welding at this time.

Explosion Welding

Explosion welding is a field process. The system could easily be adapted to welding patches for water tightness. A patch plate with a ribbon explosive could easily be placed on a hull or ponton, the explosive ignited, and the patch welded to the base metal. Some development work would be needed to package the system and provide training to use this process. Also, the section materials would have to be investigated to find out if they could withstand the explosive impact without too much distortion.

Ultrasonic Welding

This process has two major limiting factors. The first is that it requires a large clamping force between the sonotrode and the anvil. This would require that the backside of the weld be accessible; in most cases, it is not. The second factor is that the maximum thickness which can be welded is limited. Very soft materials like pure aluminum can be welded in thicknesses up to 0.10 in. (2.5 mm). Harder materials are limited to between 0.015 and 0.040 in. (.38 and 1 mm).

4 CONCLUSIONS AND RECOMMENDATIONS

When choosing a welding technique for repairing aluminum bridges, areas that should be considered are ease of use, application to bridging components, skill levels required, safety, packaging, and materials strength levels. With these factors in mind, the following processes reviewed in this study were determined to be unsuitable for field repair of aluminum bridge structures.

1. Gas welding, because it is slow and requires a great deal of operator skill.

2. Shielded metal-arc welding, because the electrodes are hard to operate, the process requires a great deal of skill, and much time must be spent cleaning the weld joint.

3. Resistance welding, because of its excessive power requirements, the size and weight of its equipment, and the required access to the back side of the weld joint.

4. Ultrasonic welding, because it requires access to both sides of the weld and because the maximum thickness which can be welded is limited to 0.1 in.

5. Electron beam welding, because the piece to be welded must be placed in a vacuum.

6. Laser welding, because it requires sophisticated equipment which cannot be adapted to field applications.

The processes found suitable for field repair were gas metal-arc welding, gas tungsten-arc welding, adhesive bonding, and explosion welding.

Gas metal-arc welding requires some operator skill and eliminates the costly slag removal process. Gas tungsten-arc welding prevents oxidation of the molten aluminum and therefore requires no welding flux. Adhesive bonding is corrosion-resistant and provides strong, durable bonds. Explosion welding is fast and economical for certain applications and has the advantage of being able to join two dissimilar metals. The first two processes have already been used in the field to repair aluminum bridging and have been shown to be relatively easy to use. Adhesive bonding and explosion welding processes are promising, but will require further research and development before they are used in the field.

It is recommended that the adhesive bonding and explosion welding processes be researched and tested as possible techniques for repairing aluminum bridging in the field.

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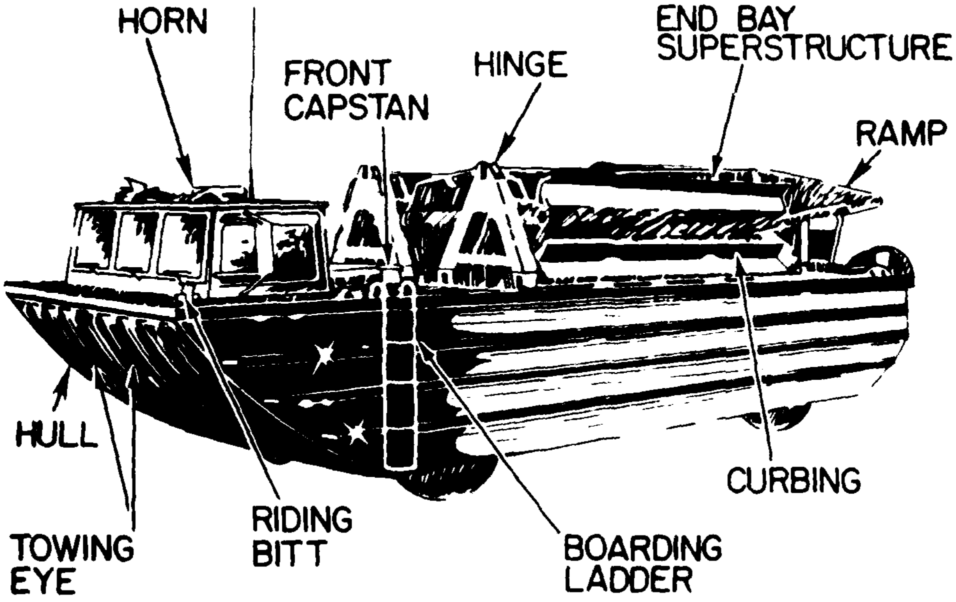

Figure 1. Transporter, mobile assault bridge/ferry with end bay superstructure installed.

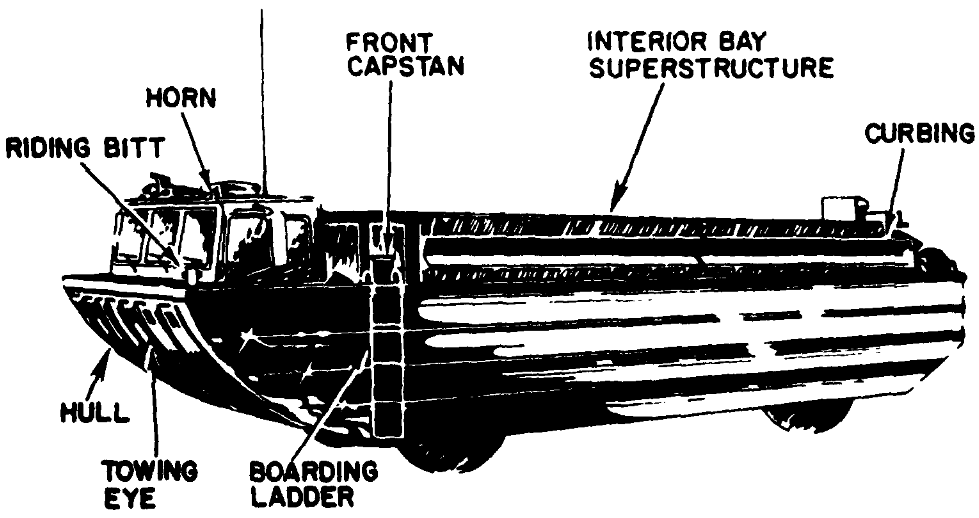

Figure 2. Transporter, mobile assault bridge/ferry with interior bay superstructure installed.

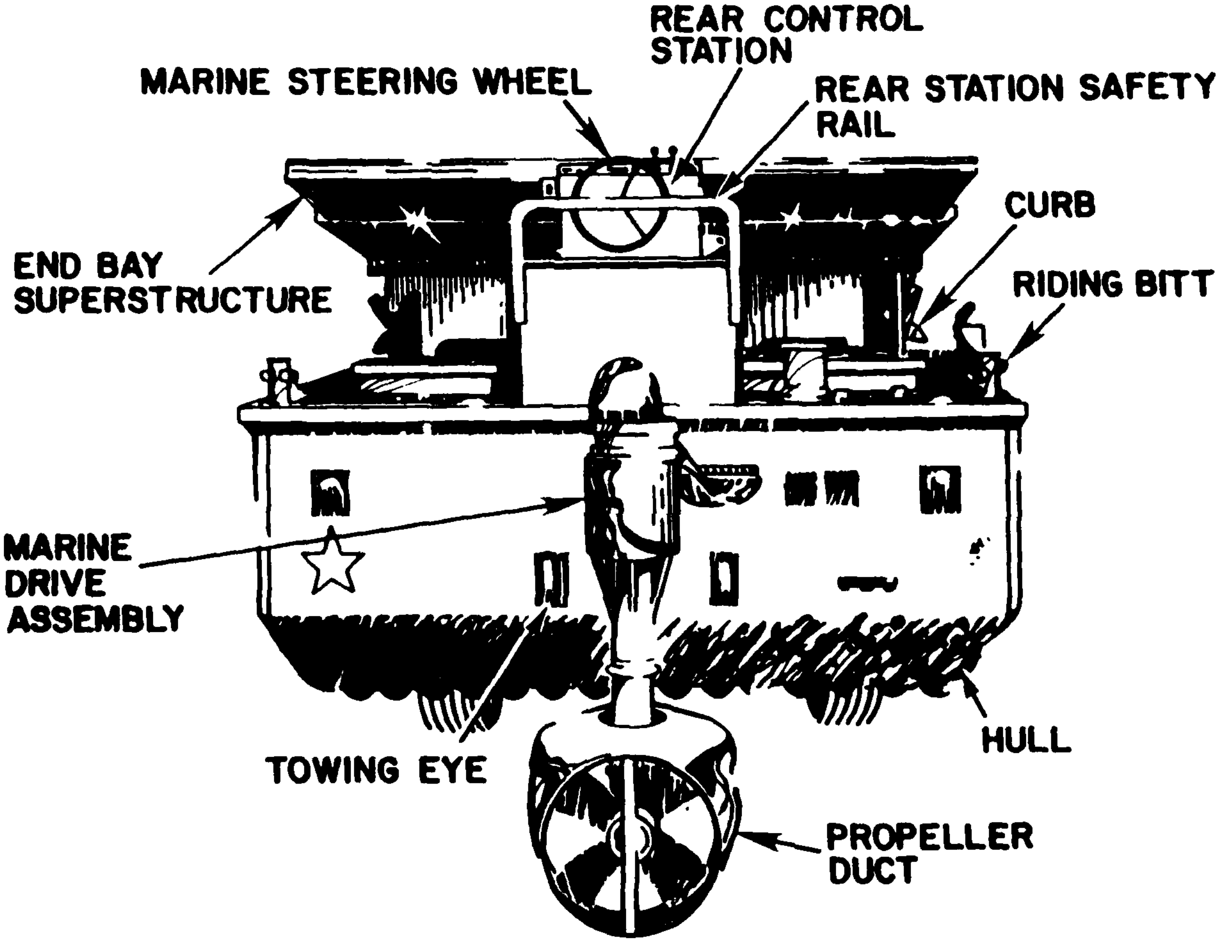

Figure 3. Stern end of transporter, mobile assault bridge/ferry with end bay superstructure installed.

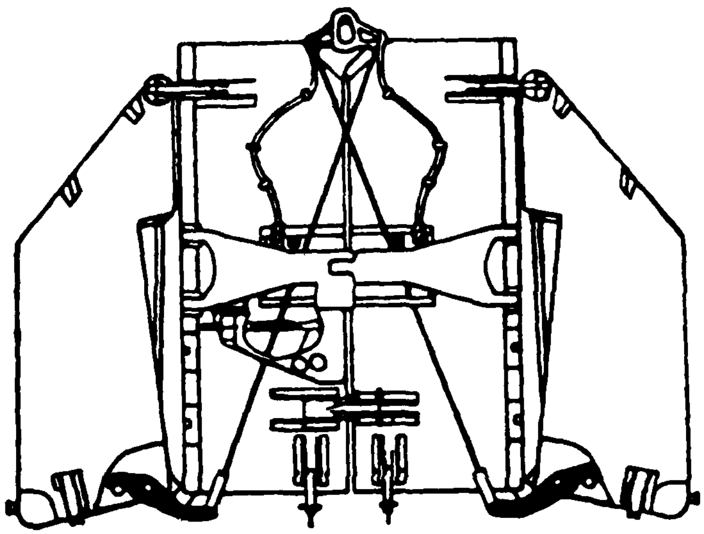

Figure 4. End view of folded interior bay section of the ribbon bridge.

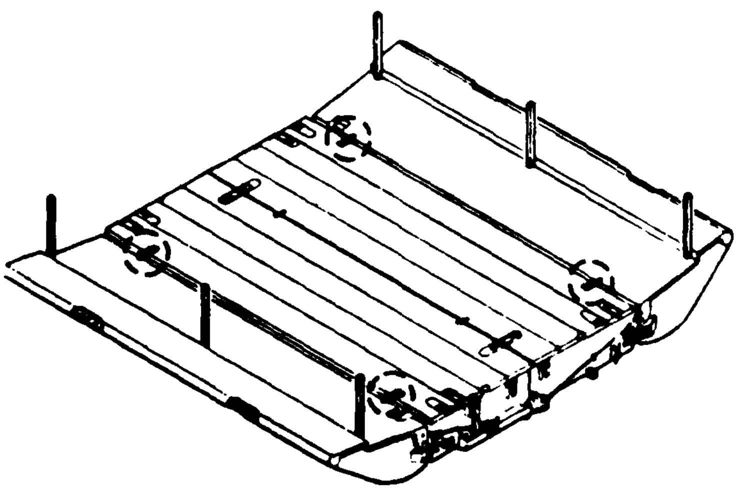

Figure 5. Interior bay section of the ribbon bridge.

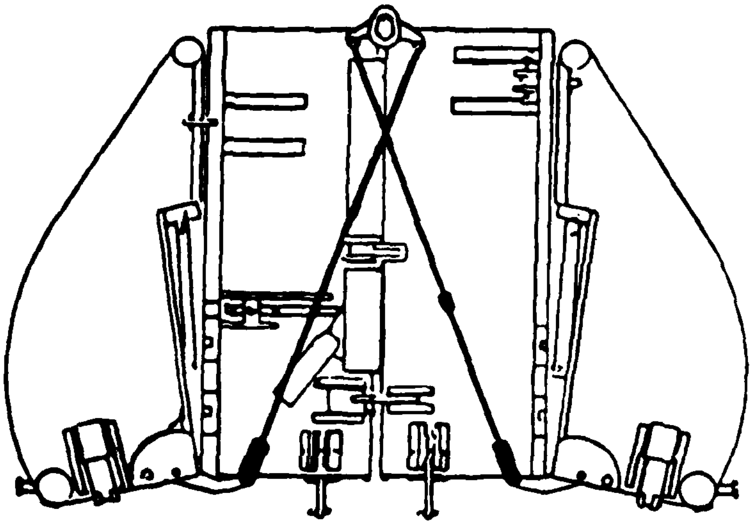

Figure 6. End view of folded ramp bay section of the ribbon bridge.

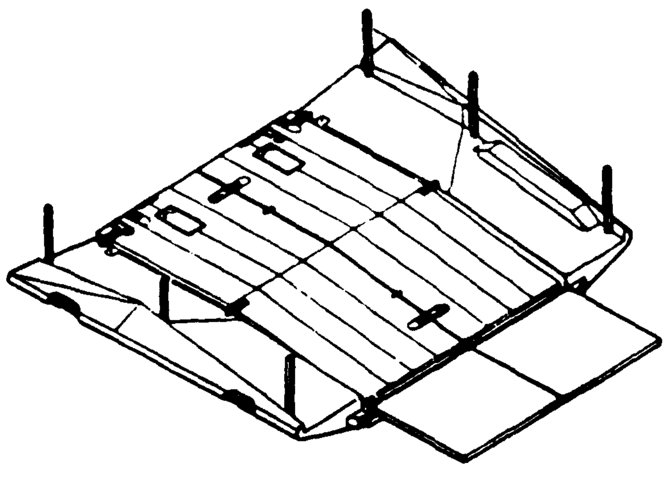

Figure 7. Ramp bay section of the ribbon bridge.

Figure 8. Off-loading the ribbon bridge from the transporter.

Figure 9. Trailer used to transport the medium girder bridge.

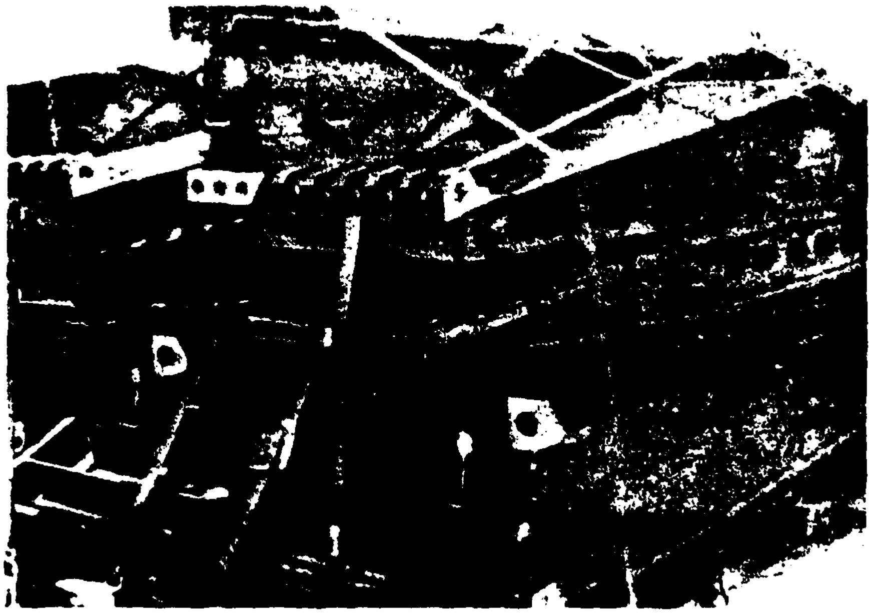

Figure 10. Medium girder bridge loaded for transport.

Figure 11. Erected medium girder bridge spanning a dry gap.

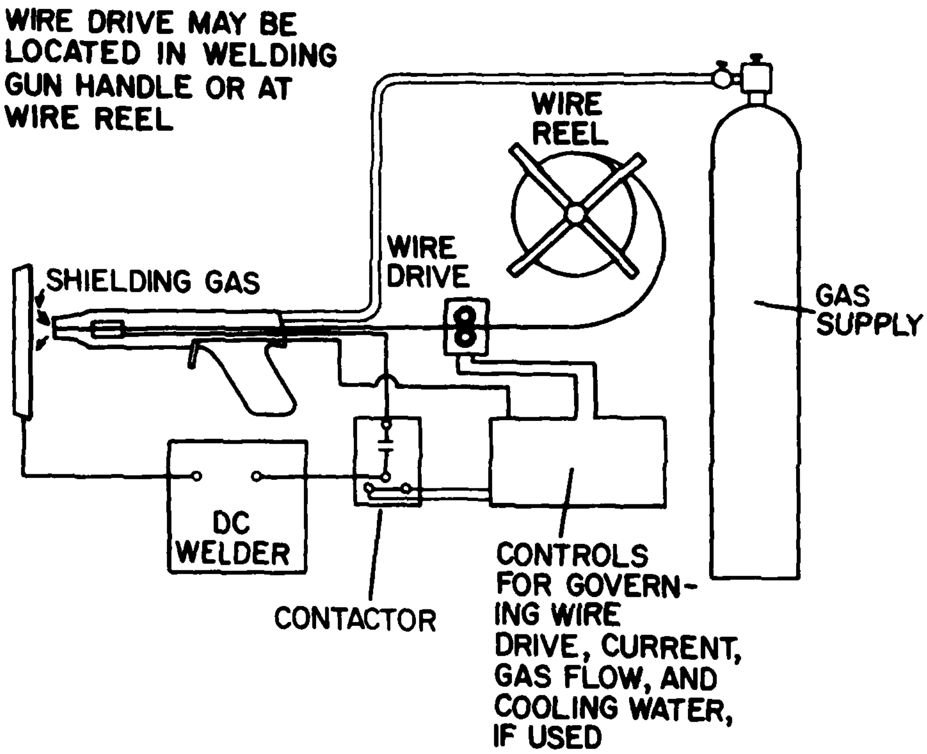

Figure 12. Schematic diagram of the gas metal-arc welding process.

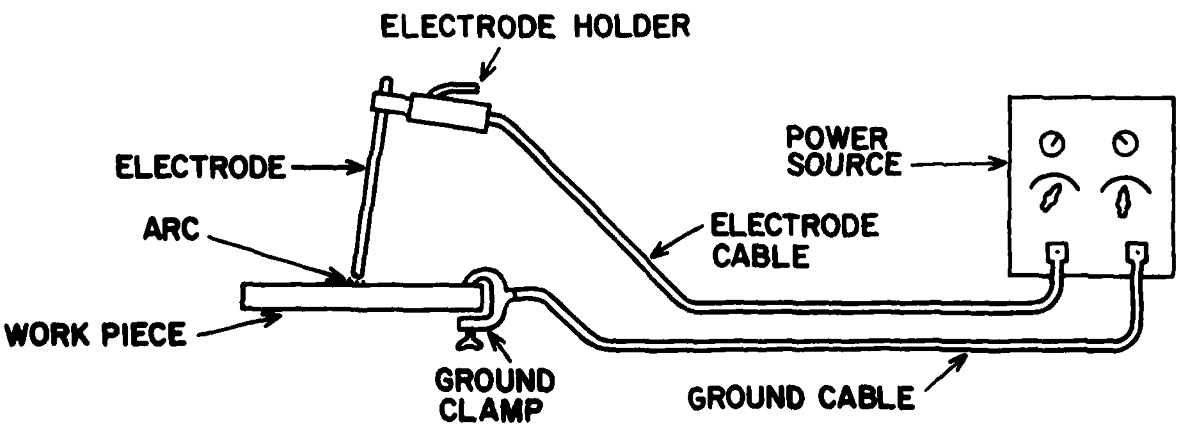

Figure 13. Schematic diagram of the shielded metal-arc welding process.

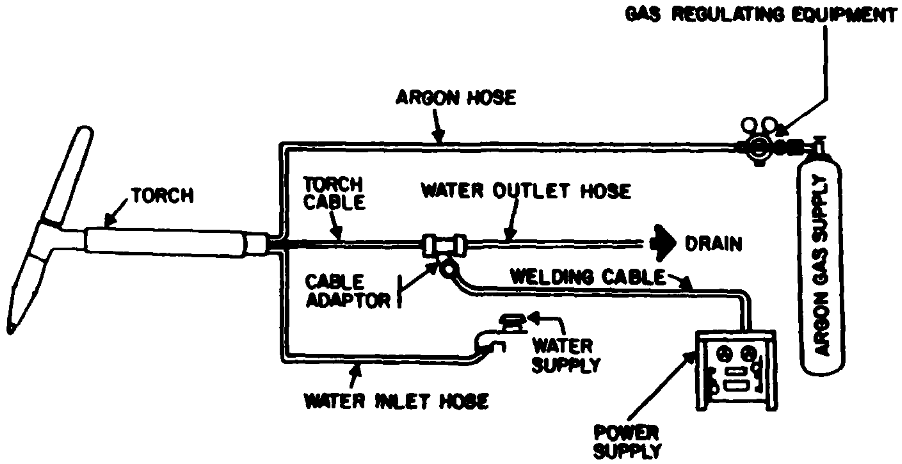

Figure 14. Schematic diagram of the gas tungsten-arc welding process.

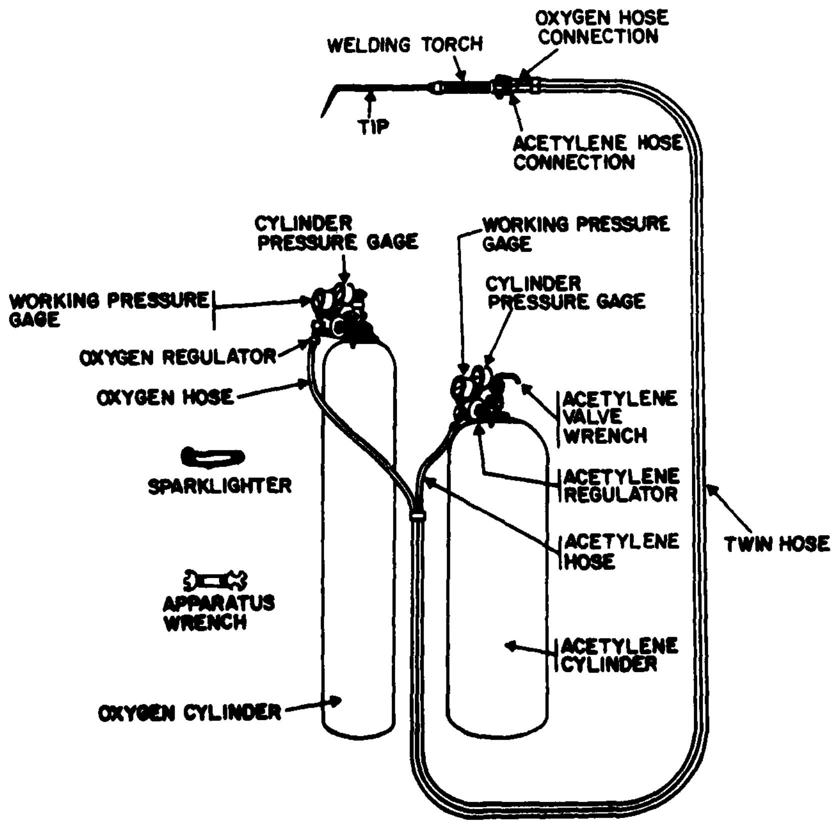

Figure 15. Portable oxy-acetylene welding and cutting equipment.

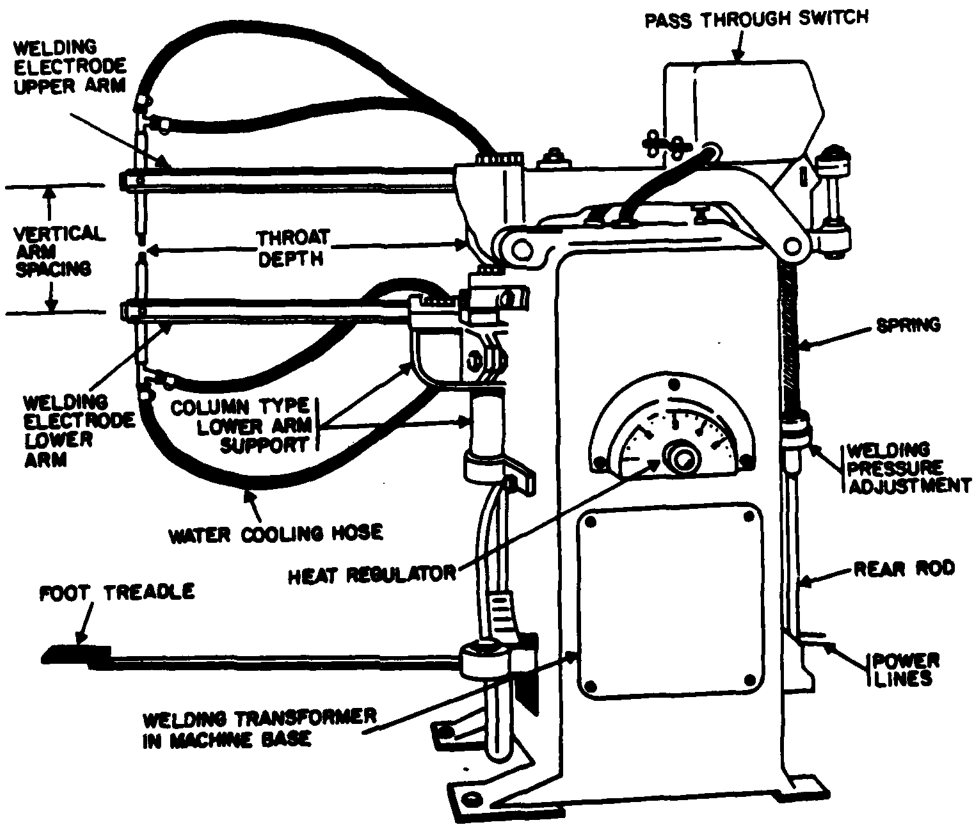

Figure 16. Resistance spot welding machine and accessories.

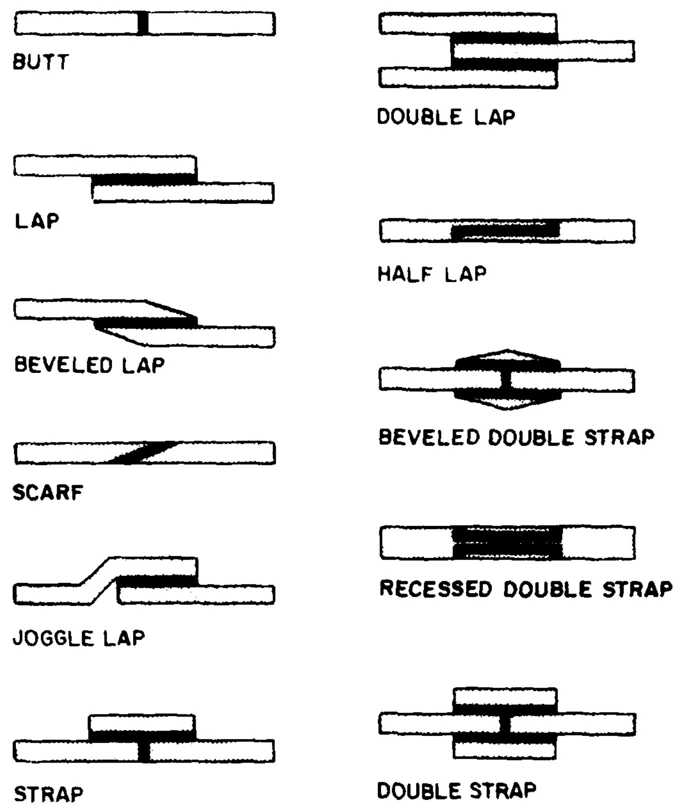

Figure 17. Joint designs for adhesive bonding.

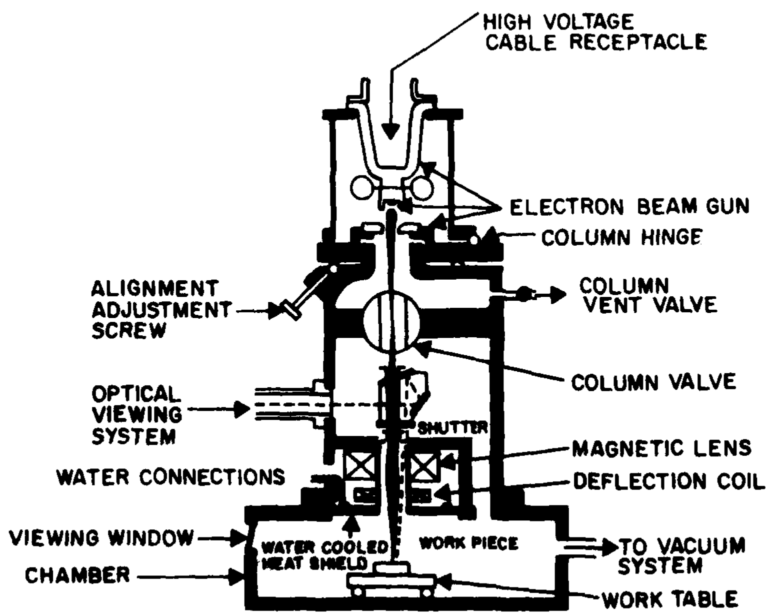

Figure 18. Typical arrangement of electron beam welder operating at potentials up to 150 KV.

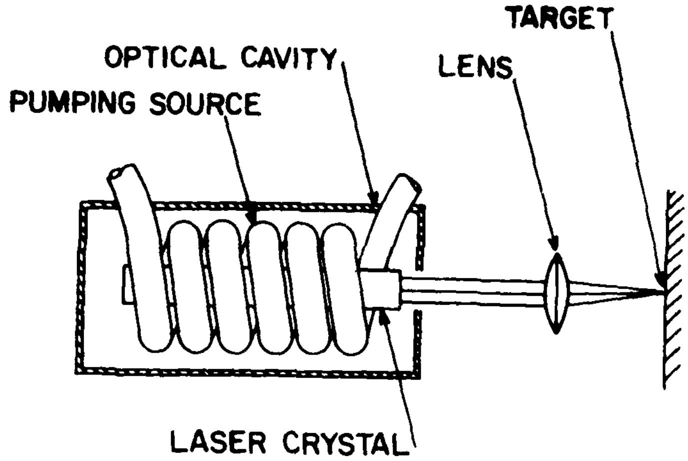

Figure 19. Gas-filled flash tube is employed to pump light into high-purity crystal rod, which is then triggered to release high-energy, single-focus light beam, melting the aluminum.

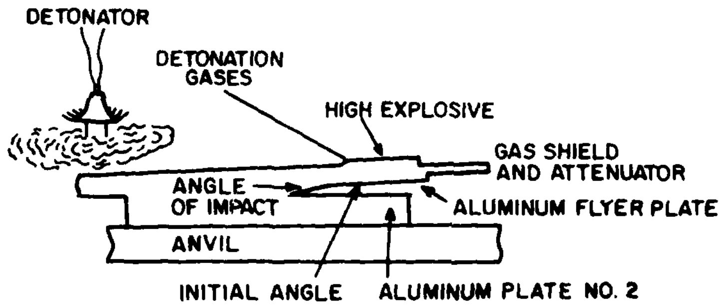

Figure 20. Schematic of the explosion welding process.

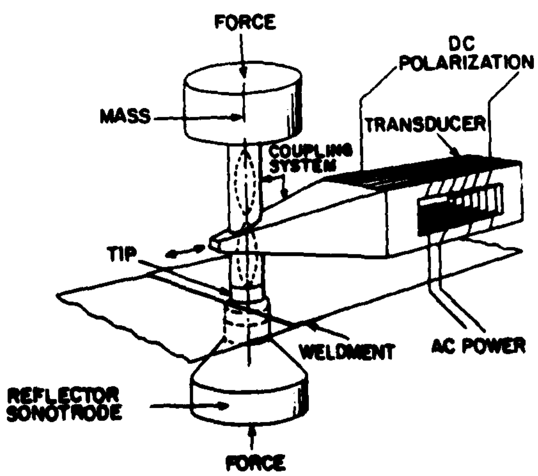

Figure 21. The wedge-reed system of transducer-coupling delivers shear waves transversely at the interfaces.

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